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Analysis of Methane Mitigation Options using the MARKAL Model for the US

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Contents

List of Figures

List of Tables

Introduction

The EPA US-national MARKAL[1] model has been recently expanded to include the ability to track methane emissions and assess mitigation strategies that interact with the energy system[2]. This methane accounting sub-model includes emission sources and mitigation technologies in the following five methane subsystems: Municipal waste and landfills; Natural gas production, transmission/storage, and distribution; Coal production; Oil production; and Manure management.

The methane sub-model in the EPA US-national MARKAL model has been developed and calibrated to perform the following functions:

1. Provide projections of future methane emissions from the energy system;
2. Assess potential mitigation levels of methane emissions by energy system component;
3. Evaluate the benefit and costs of policies, programs, and actions to reduce methane emissions;
4. Help to prioritize emission reduction opportunities in terms of cost-effectiveness and ancillary benefits, and
5. Produce emission abatement cost curves.

The Methane sub-model has been careful added as an alternate scenario to the current EPA US-national MARKAL model and integrated with the BASE scenario and other model scenarios. This enables easy running of the model with or without the Methane sub-model. In fact, the methane sub-model is essentially self-contained, and can be hooked into most MARKAL models[3].

The Methane sub-model does not make any substantive changes to the EPA US-national model resource supply depictions or Base Case results. The national model has only been partially calibrated to date, as portions of the model are still under development. For example, the model agrees with US Energy Information Administration (EIA)[4] projections of primary energy supply and CO_2 emissions, but the air pollution accounting is not yet complete so the model does not yet account for the impacts of emission constraints specified in the Clean Air Act.

This report describes analyses that were performed to demonstrate the efficacy of this new Methane sub-model[5]. These analyses investigate the effectiveness of various technologies and lay the groundwork for the formulation of policies for reducing methane emissions. A companion document[6], developed in parallel with this report contains a full description of the Methane sub-model and its use. Therefore, only an overview of the sub-model is provided in the next section of this report.

Methane Sub-Model Overview

Data on historical and projected future methane emissions was developed from various EPA documents[7], the energy projections from the EIA[8], and a few other sources[9]. A full description of the Methane sub-model and its use can be found in a companion document[6], so this report provides only an overview of the sub-model.

In each sector, the model simulates activities that produce methane, derives emission estimates from these activities (methane as well as carbon dioxide where appropriate), provides alternatives for handling the produced methane, and implements methane mitigation technologies as appropriate, based on least-cost and in response to mitigation targets imposed by the user. The nature of the methane subsystems is illustrated by part of the Municipal Solid Waste (MSW) and Landfills Reference Energy System (RES) network flow diagram in Figure 1. Similar diagrams depict each of the methane sub-system, and can be found in a companion document[6].

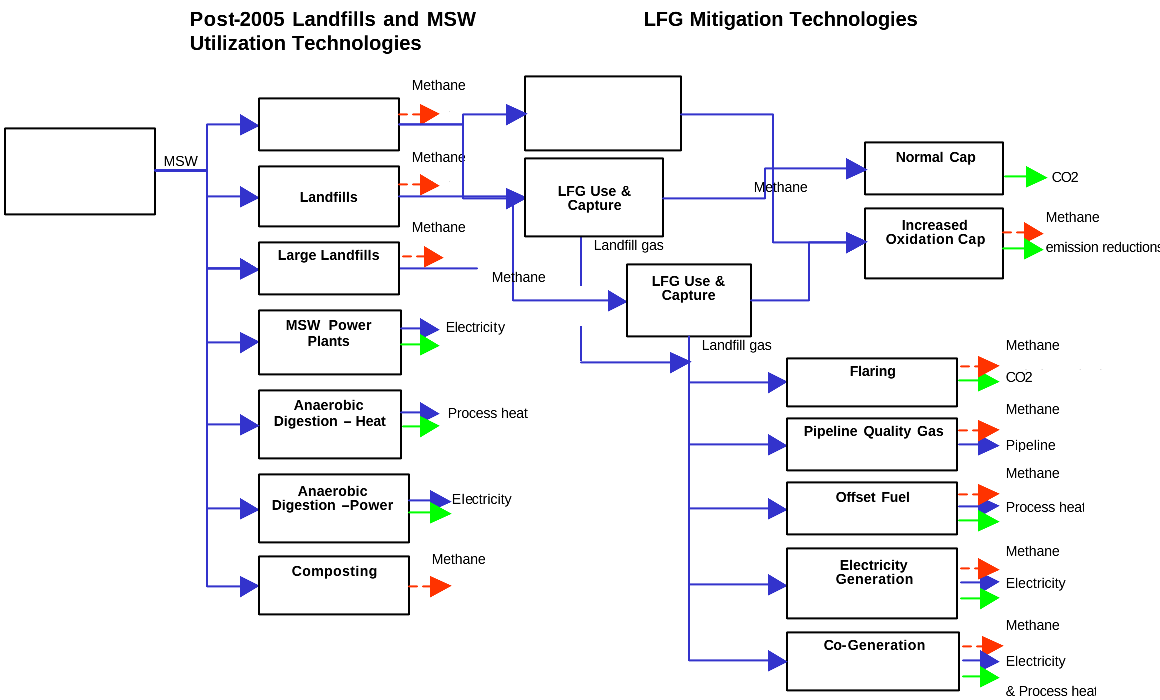

Figure 1: Methane Subsystem for New Municipal Solid Waste

Table 1 lists the numbers of emission sources and mitigation technologies that comprise the methane sub-model. As is shown in the RES diagram above, each of these is linked to one another and the rest of the energy system by means of the energy carriers that flow into and out of each technology. At the same time, in addition to the energy flows, the associated emissions (methane and other) are tracked by technology. This enables full accounting for all energy and emissions, and provides the framework within which the model chooses the optimal alternatives.

Table 1: Summary of Technologies in the Methane Sub-Model

Methane Sector	Emission sources	Mitigation technologies
MSW / Landfills	5	11
Natural Gas	3	33
Coal	40	19
Oil	4	8
Manure	4	5
Total	56	76

Municipal Solid Waste (MSW) and Landfills

Methane is generated through a biological process, which breaks down the organic materials, ferments the materials and then methane-producing bacteria converts these materials to biogas (approximately 50% methane) through an anaerobic process. The resulting emissions from landfills are divided into two categories. First are methane emissions from the pre-2005 landfills, which are based on the estimated amount of current waste-in-place. The model includes a variety of mitigation technologies that can capture landfill gas to reduce emissions from these landfills. After 2005, as depicted in Figure 1, the model tracks MSW utilization, and mitigation options are expanded to include landfills and diversion of MSW to other types of use such as composting, mechanical biological treatment, etc.

Landfills are modeled as large, medium and small to account for different methane generation rates and the applicability of the Landfill Rule[10] to large and medium landfills. Because MSW deposited in landfills will generate methane over a 30-year period, the post-2005 landfills are modeled to accept the input of MSW for one period only. They then generate methane emissions for their full 30-year lifetime. During the next period, new landfill capacity must be invested in (i.e. the expansion of landfills) to accommodate the deposit of MSW for that period. This modeling technique enable accurate tracking of the changing methane release rates over time as the waste decays. Characteristics for the MSW and landfill gas mitigation technologies were developed from EPA and other sources[11]. A companion document[6] provides a full description of the MSW and landfill portion of the Methane sub-model.

Coal Mining

Methane emissions from coal mining result when methane is liberated from the coal and surrounding strata during mining. Emissions also occur during production and transport of coal. Methane emissions from production and transport of surface-mined coal are accounted for in the model, but have no mitigation options. Underground-mined coal has several mitigation options including degasification required prior to mining, ventilation air methane capture and use, and gob gas upgrading for pipeline injection. The coal is tracked by basin as the methane release rates vary by region. A companion document[6] provides a full description of the coal portion of the Methane sub-model.

Natural Gas Production, Transmission and Distribution

Natural gas or methane emissions occur generally during the processing, with normal operations, routine maintenance, and during systems upsets. All three major stages of natural gas handling were modeled: (i) domestic gas production, (ii) processing, transport and storage of domestic and imported natural gas, and (iii) distribution to end-users. Each of the major stages (production, transmission and distribution) is modeled separately, though fully inter-connected. Within each stage, mitigation technologies specific to that stage are implemented in series allowing competing and complimentary options to be implemented.

Imported gas and other pipeline quality gas (e.g. from coal mining) are introduced into the natural gas sector after the production process. Methane that is captured in the natural gas system by mitigation technologies is added back to the flow in the next stage of the natural gas system. A companion document[6] provides a full description of the natural gas portion of the Methane sub-model.

Manure Treatment

Methane emissions from livestock manure management are generated from the anaerobic decomposition of the manure and are dependent on three principal factors: the manure source, the manure management system and the emission mitigation technology. Because liquid management systems promote anaerobic processes that generate methane, while dry management systems maintain greater exposure of the manure to oxygen and do not promote methane generation, the manure sources were grouped according to their likelihood of using liquid or slurry management systems.

Dairy cows and swine were modeled as the dominant manure sources that could use liquid manure management systems, and all other livestock were modeled as using dry treatment systems. The methane emissions from dry treatment have no mitigation options, while the liquid management systems have several mitigation technology options. A companion document[6] provides a full description of the manure portion of the Methane sub-model.

Oil Production

Methane emissions generally occur during crude oil production as a fugitive or vented emission. Emissions and mitigation options from domestic oil production are modeled for the Lower 48 and Alaska separately to allow for different emission factors and mitigation costs for these two regions. Both domestic oil sources are further segregated into on-shore and off-shore production, so that different mitigation options can be applied appropriately. A companion document[6] provides a full description of the oil portion of the Methane sub-model.

Model Calibration

In the methane sub-model calibration run, the methane mitigation options were deactivated to allow calibration to the methane emission in line with the EPA methane inventory for 1995 and 2000, and comparison of the model's projected emissions (to 2030) to the EPA baseline emission projections (to 2020 only). As can be seen in Figure 2, the base case methane emissions reported by the model from the coal, oil and manure sources closely match that of EPA, while the estimates diverge some for landfills and natural gas. For landfills, the age distribution of waste in place in existing landfills is not known with certainty, and the LFG emissions are assumed to have a linear decay rate. This is likely the reason for the difference between the baseline and base case landfills emissions. Natural gas emissions as calculated by the model are slightly different from EPA projections because the future projection for natural gas demand in the model is slightly different from that used in the EPA projection of baseline methane emissions[12]. The difference in the emissions calculated by the model is directly proportional to the difference in the natural gas demand. The smaller differences in the coal and oil sectors are also largely due to slightly different projections of energy use.

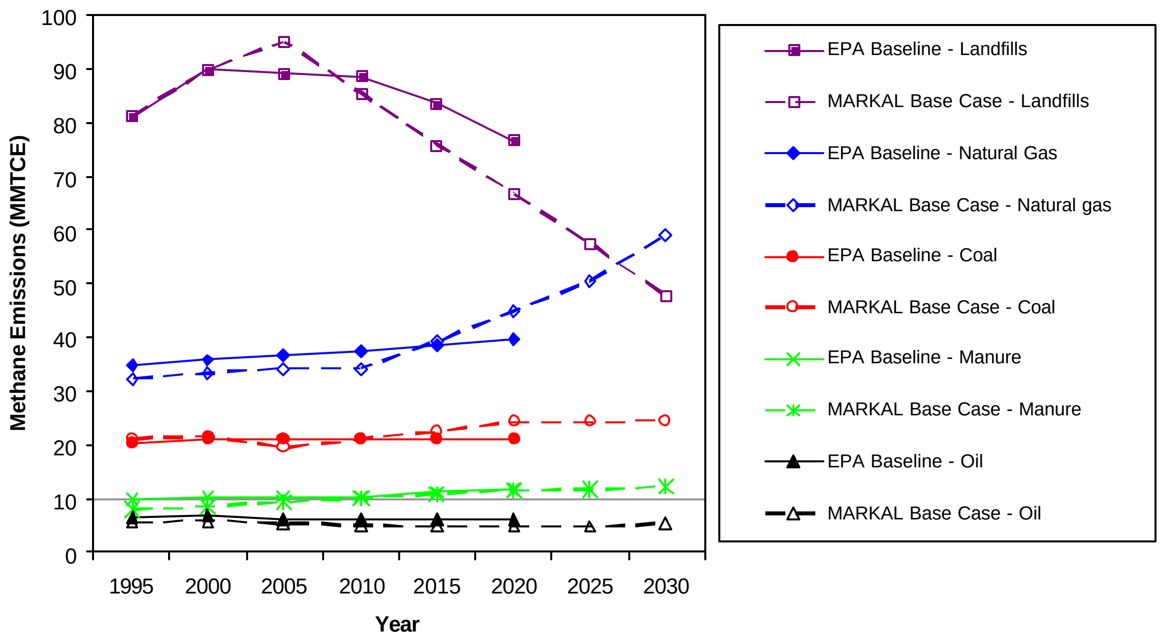

Figure 2: Methane Sub-model Calibration to EPA Baseline Projections

Methane Mitigation Scenarios

Using this model, analyses were performed to investigate the effectiveness of various technologies and policies for reducing methane emissions. Specifically, the following five scenarios were run.

1. Methane Base Case. As with the USEPA projections, this model run contains no mitigation technologies and provides a baseline for evaluation by the model of which mitigation technologies are most cost-effective. This case is the same as the calibration run, and referred to as the Base case below.

2. Adoption of Cost-Effective Options. For this case, the mitigation technologies were added to the model and allowed to be selected by the model on a strict economic basis only (i.e., adoption of some methane technologies leads to lower energy system costs compared to only the Base Case technology choices). Comparison of this case to the Base case provides a measure of the benefits that can be achieved by facilitating entry of all cost-effective methane handling technologies into the market. This case was used as the Reference case, and serves as the comparison case for the following runs.

3. Fuel price sensitivity. For this case the Reference scenario was run using a projected high oil and natural gas price scenario from EIA.

4. Methane Reduction. For this scenario, four illustrative model runs were made in which methane emissions were reduced 10%, 20%, 30% and 50% below the level of emissions in the Reference scenario, to be achieved in 2030 progressively starting in 2005.

5. GHG Reduction. For this scenario, combined emissions of methane and CO_2 were modeled based on their relative global warming potential. A value of 21 was used for methane[13] relative to carbon dioxide, and three illustrative emission reduction runs were developed of 10%, 20% and 30% in the same manner as the methane reduction policy run.

Scenario Results

In 1995, the Base case methane emissions are about 25.8 million metric tons, or 148 million metric tons of carbon equivalent (MMTCE), which grow to about 163 MMTCE in 2005 before dropping somewhat to 148 MMTCE by 2030. Most of this reduction is due to decaying emissions from the pre-2005 landfills, and EPA projections for waste reduction programs and diversion of MSW from landfills to alternative uses.

Reference Scenario

In the Adoption of Cost-Effective Options, the Reference scenario for the sensitivity runs, shown in Figure 3, methane emissions increase from 1995 levels to a bit over 150 MMTCE in 2005 and drop to about 120 MMTCE by 2030. Most of this reduction is due to cost-effective uses of on-site electricity generation using municipal solid waste (MSW) and landfill gas (LFG), farm-scale electricity generation using manure digester technology in warm climates, coal mine degasification, and dry seals on centrifugal compressors used in natural gas production.

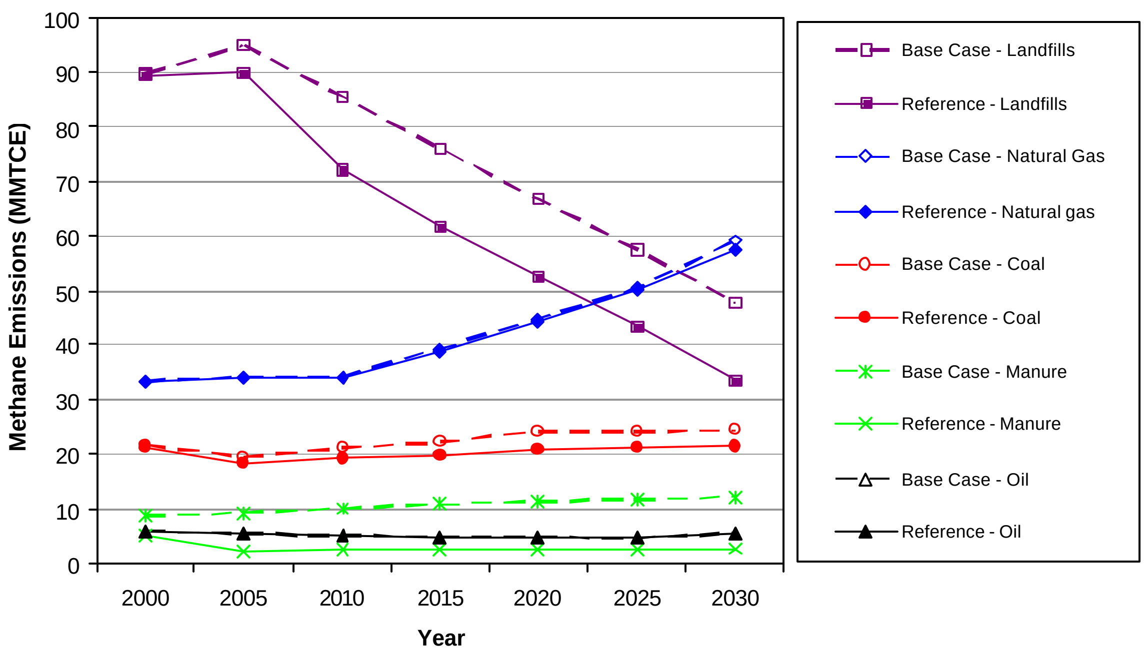

Figure 3: Comparison of Base Case (No Methane Mitigation Options) and Reference Scenario (Methane Options Permitted, But No Emission Constraint)

High Oil and Gas Price Scenario

Given the uncertainty in fuel prices, a scenario was developed based on the High Oil and Natural Gas Price scenario from the EIA[14], where prices are approximately 1.35 times their base case values. In this scenario, the cost of all imported and domestic crude oil and all imported petroleum products as well as domestic and imported natural gas supplies were increased by this factor. The methane emissions from this scenario are illustrated in Figure 4, where it can be seen that there is a slight additional reduction in the methane emissions from the coal and natural gas sectors. Overall, the consumption of natural gas decreases by 3 and 7% in the last two time periods, but the reduction in methane emissions from this sector decreases by less because most of the reduction comes in imported natural gas. For the oil sector, all the reductions in consumption occur in imports, and there is no decrease in emissions from this sector. More coal is used in place of the reduced oil and gas imports . Yet, in spite of the increased coal use, which reaches 10% in the last period, methane emissions actually decrease by as much a 4%, because more coal mine degas capture projects become cost-effective with the higher natural gas price.

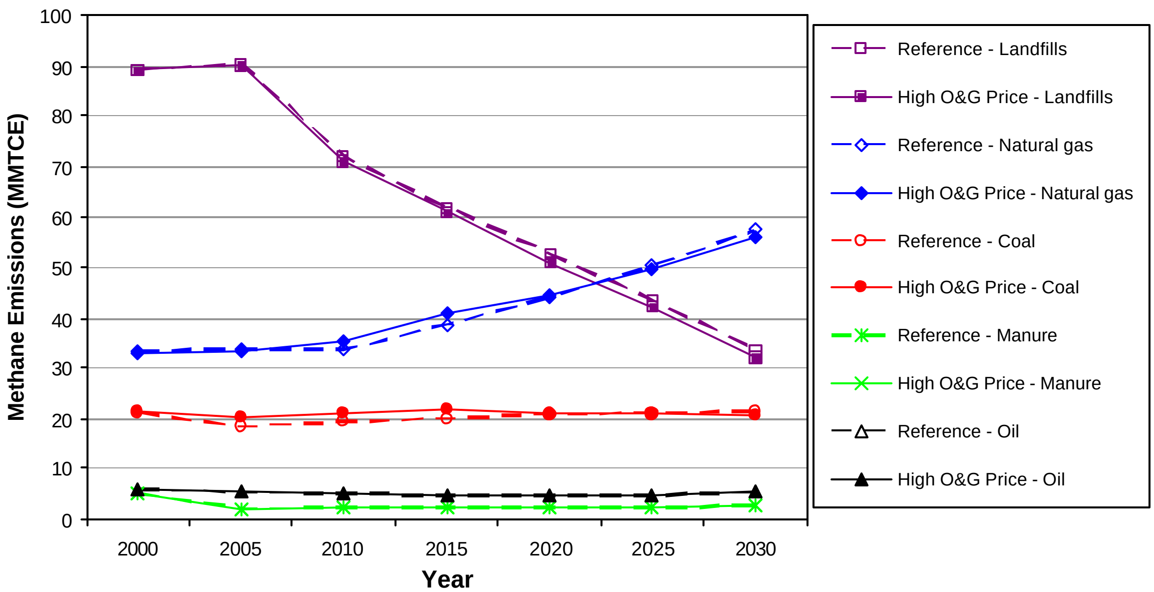

Figure 4: Impact of High Oil and Gas Prices on Methane Emissions

Methane Reduction Scenario

For the Methane Reduction scenario, four runs were made with reductions in methane emissions throughout the energy system starting in 2005. The reductions were made from the Reference case (the one permitting the adoption of cost-effective options) methane emission levels with target reductions of 10%, 20%, 30% and 50% being achieved in 2030 based on a linear ramp to the target level starting from period 2005 levels.

The result of three of the methane reduction runs are illustrated in Figure 5. With a 10% reduction, most of the additional methane reductions come from the coal sector, through the capture of gob gas from new mines, the utilization of coal mine methane (CMM) as supplemental fuel and the flaring of ventilation air. With a 20% reduction, more coal mine methane is flared and additional landfill gas is both flared and used for supplemental fuel. In the 50% reduction case, several mitigation technologies in the natural gas sector are utilized along with additional reductions of CMM and LFG, pretty much eliminating the latter as a source of methane by the end of the modeling horizon. In the 50% methane reduction case, significant reductions from the oil production sector are also seen.

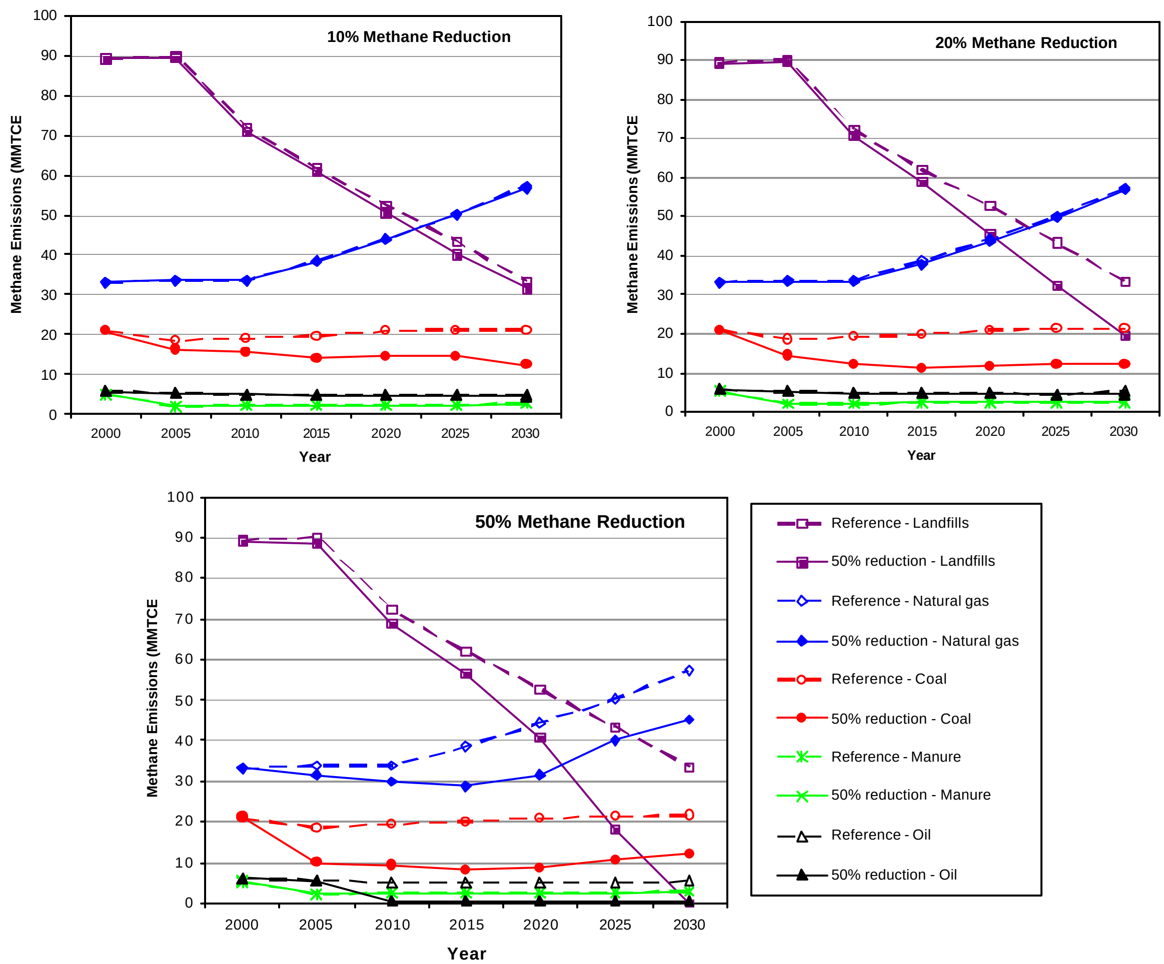

Figure 5: Methane Reduction Scenario - 10%, 20% and 50% Reductions

GHG Reduction Scenario

In the GHG Reduction scenario, both CO_2 and methane are being constrained, and these runs represent the first analyses performed to date that exercise the CO_2 mitigation technologies in the national model's Base scenario. In fact, a set of coal gasification technologies with CO_2 capture and sequestration were added to the Base scenario to facilitate these runs.

Figure 6 presents the methane emission reductions that are generated when both gases are constrained. With a 10% GHG cap, the methane reductions come primarily from the landfill and coal sectors. Because of the GHG cap, coal use is reduced and natural gas use is increased, with the increase coming mostly from imports, so there is no change in emissions from that sector. It is important to note that the 10% GHG Reduction scenario results in significantly more methane reductions than the 10% Methane Reduction scenario. In fact, the 10% GHG reduction run mitigates the same amount of methane as the 30% methane reduction scenario. Methane represents 6% of the cumulative GHG emissions in the Reference Case. The 10% GHG Reduction scenario reduces methane emissions by 12% and CO_2 emissions by only 5%, which indicates that the methane reductions are generally more cost-effective than the CO_2 reductions and that the combined GHG reduction strategy is generally more cost-effective than the CO_2 reductions only.

As the GHG reduction amount increases, the additional reductions continue to come from increased capture and use of landfill gas and from reductions in coal use, and the corresponding emissions that would be generated from coal mining. This is partially offset by increased methane emissions from the natural gas sector, which are due to its increased use. Very little reductions come from the oil sector in this scenario compared to the Methane Reduction scenario.

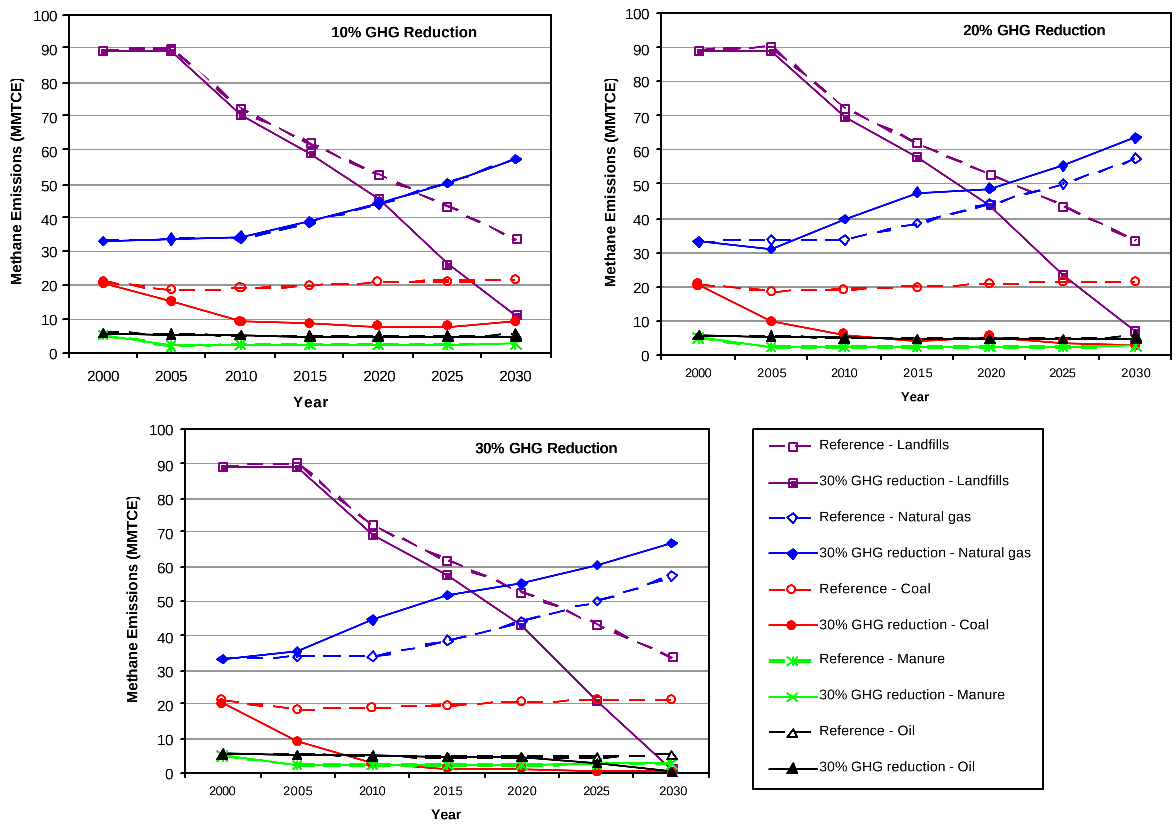

Figure 6: GHG Reduction Scenario - 10%, 20% and 30% Reductions

Emission Reduction Cost Curves

Continuous Emission Reduction Cost Curves

The results of the scenarios discussed above were used to generate various forms of emission reduction cost curves. The most basic of these is the Continuous Emission Reduction Cost curve (CERC), shown in Figure 7 for methane. It illustrates the increase in the total energy system cost that results from mandated reductions to be achieved in the 2030 methane emission levels, with linear constraints from the 2005 levels. The figure plots cumulative methane emissions over the modeling period (1995-2035), expressed in million metric tons of carbon equivalent (MMTCE), against the total discounted system cost (in millions of 1995 US$). The CERC reflects all the changes occurring throughout the energy system in response to meeting the stated emission reduction target, including the introduction of more advanced technologies, fuel switching and the employment of methane mitigation options. The steep nature of the curve to reach the 10% reduction indicates that achieving that goal can be done with relatively little increase in overall cost, whereas the flattening of the curve between the 30% and 50% points clearly indicates that less cost-effective mitigation options have to be employed to achieve the constraint. While the CERC curves provide an instant overview of the cost versus mitigation goal, they give little insight into the specific choices made by the model.

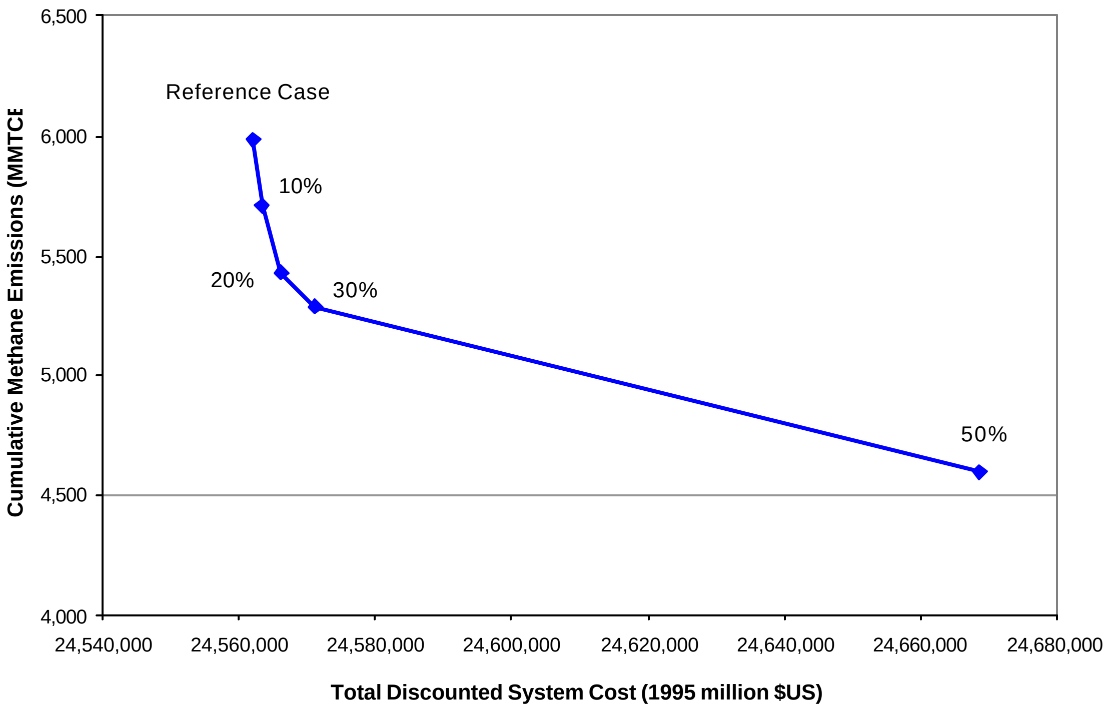

Figure 7: Continuous Methane Emission Reduction Cost Curve

Figure 8 presents CERC curves based on **total** GHG emission reductions for three sets of runs; the four Methane Reduction runs, two of the GHG Reduction runs, and the two CO_2-only runs that were made for comparison purposes. In this figure, each curve uses the Reference scenario as the common starting point. In the methane reduction runs, the GHG emissions are generally flat, because of several reasons. First, the methane reductions are partially offset by the CO_2 released by methane mitigation options involving flaring and combustion. Second, with no constraint on CO_2, the model allows substitution of coal and oil for natural gas to reduce methane emissions from the natural gas production, transmission and distribution sector.

The CERCs for the CO_2-only reduction runs must be considered very preliminary because of needed improvements in the calibration of the Base scenario in the model. These improvements include completion of the air pollution emissions accounting and validation of model results at the sub-sector level. The figure shows that the CO_2-only reduction runs and the GHG reduction runs are relatively close, but that the GHG runs achieve the equivalent reductions with a savings in the total discounted system cost of $910 million. This result should be considered very preliminary, as mentioned above, but it is consistent with other economic models of climate change, which have demonstrated that multi-gas abatement strategies significantly reduce costs versus achieving the same level of GHG reductions through CO2 strategies alone[15,16,17,18,19].

The model selects some different mitigation technologies in the CO_2-only reduction runs compared to the methane reduction runs and the GHG reduction runs. One of the more interesting ones is that flaring options for CMM and LFG, which are heavily selected in the latter two types of runs and not selected in the CO_2-only reduction. These technologies release CO_2, and in the CO_2-only reduction runs, the model instead selects mitigation options that substitute CMM or LFG for natural gas.

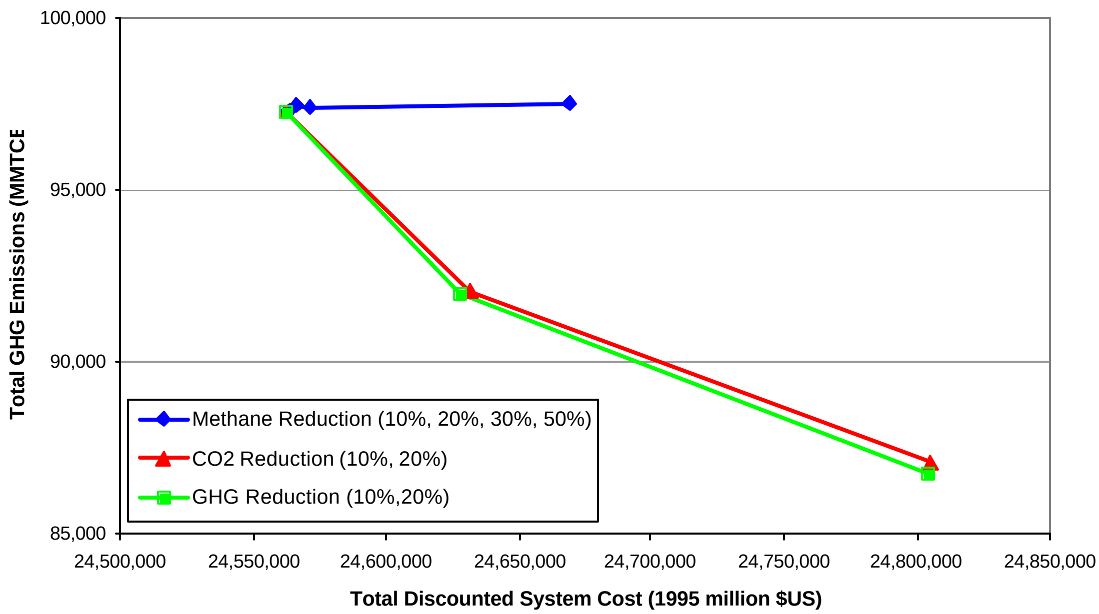

Figure 8: Continuous GHG Emission Reduction Cost Curve

Cumulative Methane Mitigation Cost Curves – Methane Reduction Runs

As noted earlier, the Continuous Emission Reduction Cost curves represent the action of the entire energy system, and simply show the trade-off between total system cost verses total emissions, providing no insight into technology choices. However, since the methane sub-model tracks methane emissions and reductions at the technology level, we can also generate two other types of emission reduction cost curves that contain information on the specific mitigation options employed by the model.

The Cumulative Methane Mitigation Cost curve (CMMC), shown in Figure 9, for the Reference case and three of the methane reduction runs, is developed by ordering the unit mitigation cost for each technology employed in an ascending order (cheapest to most costly) and plotting the cumulative cost of deploying each mitigation technology against the cumulative amount of methane mitigation achieved. These curves correspond closely to the Marginal Abatement Cost curves (MAC) presented in the EPA report[5], but differ from them in that they illustrate only the options that are implemented in order to reach the target (not all potential options).

The curves in this plot also show some variations due to the timing of investments made by the model and variations in the utilization of the selected technologies. The figure shows that the cost of reaching a 20% reduction in methane emissions is only slightly higher than the cost of only achieving a 10% reduction, but to reach 50% the mitigation costs will increase 3-fold, as substantially more expensive mitigation options must be selected to meet the more stringent constraint.

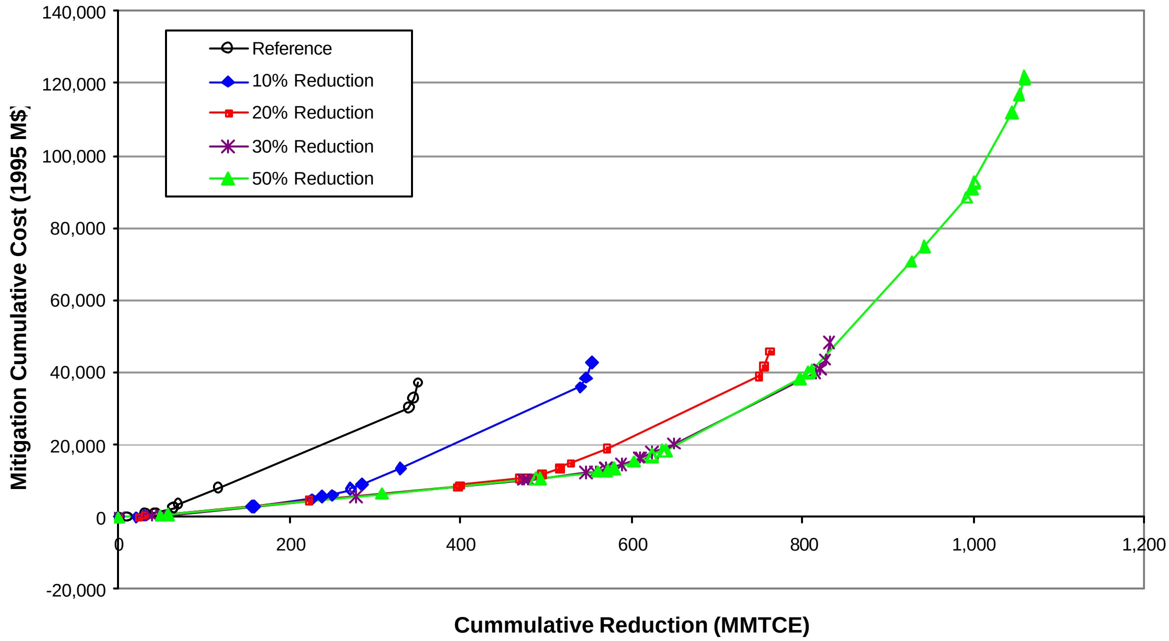

Figure 9: Cumulative Methane Mitigation Cost Curve - 2000 to 2030

Each of the CMMC curves is scenario specific, with the timing of the investments and the level of mitigation needing to be done by the various selected options varying, resulting in shifting of the curves to the right as the emission levels are tightened. For example, referring to Table 2 below, one can see major increases in the amount of mitigation that needs to be done (in the later periods when the constraints are more severe) by process heat from CBM and flaring of gas form landfill and coal mines, the 2nd, 4th and 5th most cost-effective options, as the methane constraint is tightened. The two more expensive options that result in the sharp vertical "spike" at the end of the curves are electricity generation options in the manure and landfill gas sectors, where though appearing expensive compared to the other mitigation options they actually represent cost-effective electricity generation options versus conventional power generation in certain situations, particularly when emission limits are imposed.

MARKAL can also provide an additional indicator of the attractiveness of individual technologies. By imposing an explicit limit on the penetration level of a technology the optimization algorithm will report the marginal cost, or desire of the model to have another unit of each technology. The larger (more negative) the marginal value the more would like to have another unit of said technology.

Mitigation Technology Cost Effectiveness

Table 2 lists the principal methane mitigation technologies selected by the model to achieve emission reductions in all of the runs discussed above, ordered by their cost-effectiveness, i.e. cost in 1995 dollars per metric ton of carbon equivalent ($1995/MTCE).

The table shows the order in which the model tends to select the technologies, starting with the set used in the Reference case and then showing which technologies were added in the 10%, 30% and 50% methane reduction cases along with the actual emission reduction amount expressed in cumulative MMTCE over the years 2000 to 2030.

For most of the technologies, there is either a constant use of the technology, or a progressive increase in the use of the technology. However, there are some interesting technology switches in the CMM and landfill sectors. For example, the 30% reduction case uses a lot more flaring at landfills, and it needs to bring this technology on relatively soon. As a result of this earlier investment, not as much landfill gas cogeneration is used as in the 10% case. Similarly, the 50% reduction case needs to use the increased oxidation cap for landfills, and as a result there is a further reduction in landfill gas cogeneration. On the coal side, there is both an overall reduction in coal use, along with an increase in early investment of CMM for process heat supply, which results in a reduction in cogeneration using CMM.

Table 2: Mitigation Technology Cost Effectiveness and Mitigation Amount

Mitigation Technology	$1995/MTCE	Mitigation amount (cumulative MMTCE)			
		Reference	10% Reduction	30% Reduction	50% Reduction
Dry Seals on Centrifugal Compressors (Natural Gas Process & Transmission)	-417	0.6	0.6	0.6	0.6
Process Heat Supply from Utilization of Coal Mine Methane	13		20.2	39.1	47.7
Redesign Blow -down/ESD (Natural Gas Transmission & Storage)	21	8.8	8.8	8.7	8.0
Flaring of Landfill Gas	22		2.5	229.5	251.5
Flaring of Coal Mine Methane	23		126.0	196.8	180.6
Capture and Upgrade of Gob Gas from New Coal Mines	26	0.0	0.0	0.0	0.0
Fuel Gas Blow -down Valves (Natural Gas Process & Transmission)	28			3.8	4.7
Capture and Upgrade of Landfill Gas for Pipeline Injection	30	21.1	67.4	68.2	67.8
Capture and Upgrade of Gob Gas from Existing Coal Mines	36	11.4	11.4	11.4	11.0
Gob Gas Upgrade - New Vented Mines	40	1.5	13.2	11.7	8.0
Hot Taps (Natural Gas Transmission & Storage)	45		0.4	0.4	0.3
Farm Scale Digesters-B (cool climate)	72	0.2	0.2	0.2	0.2
Landfill Gas used for Supplemental Fuel	78			17.9	22.6
MSW Anaerobic Digestion 1 - Process Heat	82	20.9	20.9	20.9	20.9
Centralized Digesters (cool climate)	86	0.3	0.3	0.3	0.3
Electricity Generation using Landfill Gas	95	4.8	12.5	12.1	12.5
Low-bleed Pneumatic Devices (Natural Gas Production)	95			1.7	3.4
Co-Generation using Landfill Gas	125	222.6	211.7	164.2	156.9
Co-Generation using Coal Mine Methane	187	46.9	44.5	27.0	10.6
Flaring of Natural Gas Emissions from Production	240			0.0	2.0

Mitigation Technology	$1995/MTCE	Mitigation amount (cumulative MMTCE)			
		Reference	10% Reduction	30% Reduction	50% Reduction
Increased Oxidation Caps for Landfills	258			5.4	116.8
Flaring of Associated Gas – Onshore Oil Production - Alaska	264			0.0	16.2
Flaring of Associated Gas – Onshore Oil Production – Lower 48	272			0.0	49.0
Flaring of Natural Gas Emissions from Transmission and Storage	395			0.0	0.2
Farm Scale Digesters-B (warm climate)	430	6.0	6.0	6.0	6.0
Utilization of Associated Gas – Offshore Oil Production – Alaska	442				3.8
Low-bleed Pneumatic Devices (Natural Gas Process & Transmission)	443				0.3
Utilization of Associated Gas – Offshore Oil Production – Lower 48	452				42.9
Gas turbines replace reciprocating engines (Natural Gas Process & Transmission)	505				9.1
MSW Anaerobic Digestion 2 - Electricity	714	6.2	6.2	6.2	6.2
Electronic Monitor at Large Surface Facilities (Natural Gas Distribution)	874				0.4
Use smart regulators/clocking solenoids (Distribution)	1000				0.3
Reduce Glycol Circulation Rates in Dehydrator (Prod)	1175				0.0
MSW Power Plant 1	1349	18.1	45.7	45.7	45.7
P&T-D I&M (Compressor Stations: Enhanced)	1524				0.0
Catalytic Converter (P&T)	1698				0.2
DEGAS Capture: New Coal--App., Bit., MSU	1873	0.0	0.1	0.1	0.1
DEGAS Capture: New Coal--App., Bit., HSU	2048				0.0

Cumulative Methane Mitigation Cost Curves – GHG Reduction Runs

Continuous methane mitigation cost curves were also generated for the three combined GHG reduction runs, as shown in Figure 10. There are several observations worth noting regarding the curves. First, unlike the methane-only reduction runs, the amount of methane reduction achieved does NOT necessarily follow that of the GHG mitigation levels. As the GHG constraint gets more severe there is a major shift to imported natural gas at the expense of coal, particularly underground, which limits the methane reduction opportunities and results in less mitigation of methane. But for intermediate levels of GHG reduction mitigation of methane plays an important role with the cumulative level of methane reduction corresponding to a direct methane-only reduction of about 20%.

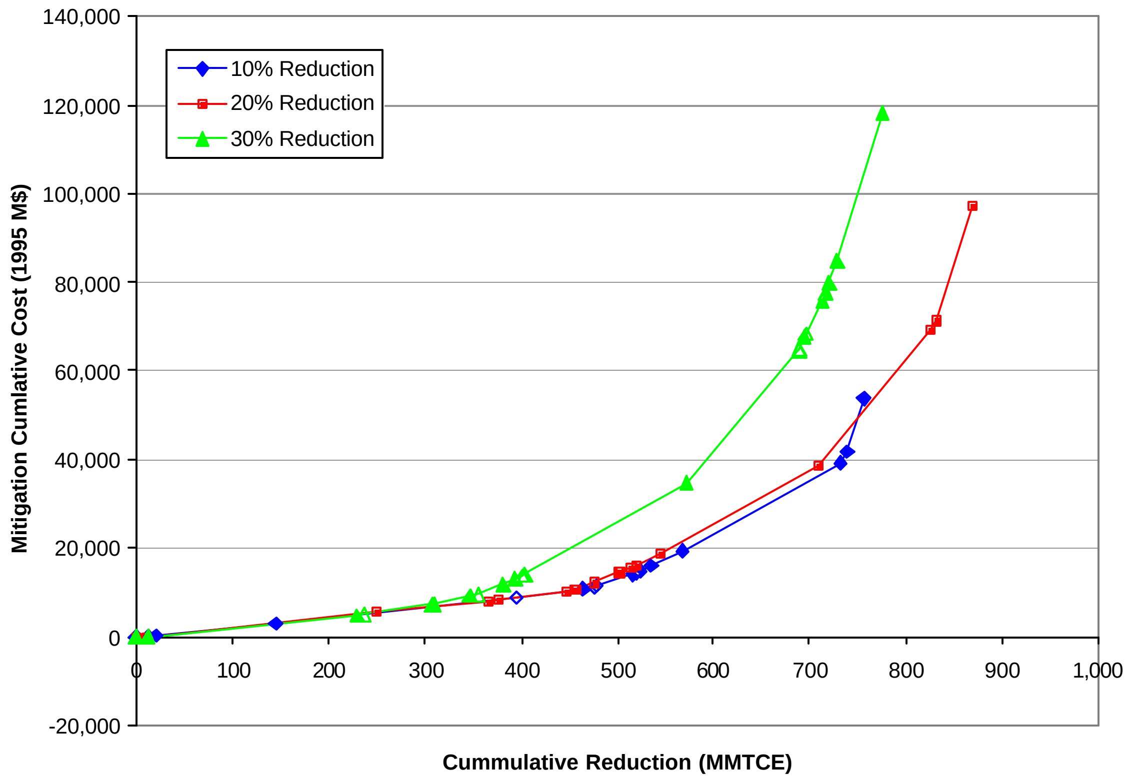

Figure 10: Cumulative Methane Mitigation Cost Curve - GHG Reduction Runs

Marginal Cost of GHG Reductions

The importance of bundling emission reduction targets to include both CO_2 and methane is reflected in the impact on the marginal reduction cost, or the cost of avoided CO_2 equivalent, for CO_2-only verses GHG targets. As seen in Table 3 below, the GHG reduction targets are reached at lower cost, with the marginal cost averaging 16% less for the 10% GHG run and 2% less for the 20% GHG run when the more cost-effective methane reduction options are available to meet the overall mitigation target. Currently, when constraining methane, there is pressure to keep coal and gas use down, which limits methane availability, leading to some periods where the GHG mitigation costs are slightly above the CO_2. However, it is again noted that at the moment there only a few explicit CO_2-only mitigation options (e.g. coal gasification power plant with CO_2 sequestration) included in the base model, and these results must be viewed as preliminary.

Table 3: Marginal Reduction Cost of CO2 and GHG ($1995/MTCE)

Scenario	2005	2010	2015	2020	2025	2030
CO2 Reduction by 10%	3,873	5,689	5,074	13,004	18,372	23,470
CO2 Reduction by 20%	11,300	11,262	12,983	15,580	32,218	47,780
GHG Reduction by 10%	3,377	5,175	4,819	11,241	13,322	16,615
GHG Reduction by 20%	10,317	12,266	12,762	15,878	33,656	46,643

Conclusions

This report illustrates the capabilities and types of analyses that can be performed with the Methane sub-model that has been added to the EPA US-national MARKAL model. The model can be used to investigate policies and strategies to encourage the use of cost-effective energy supply options embedded within the methane system and it can examine the relative effectiveness of possible programs looking to mitigate GHG emissions. From the modeling point of view the complexities of the methane emission sectors and their interactions with the energy system are represented in appropriate detail. The scenarios investigated in this paper were exploratory and serve to illustrate the possible technology and policy options that can be investigated with the model; and the continuous and cumulative mitigation cost curves providing insight into programs that might stimulate the market to more quickly adopt the more cost-effective mitigation options.

A very powerful capability of the EPA US-national MARKAL model is its ability to model technology and policy options for both CO_2 and methane mitigation based on their relative global warming potential. The results of the mitigation scenarios performed for this paper illustrate the increased cost-effectiveness of such combined strategies. To this end, expanding the emission coverage to include the rest of the GHG contributors is planned, permitting a complete picture of options and opportunities to reduce GHG emissions in the most cost-effective manner to be examined with the model.

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